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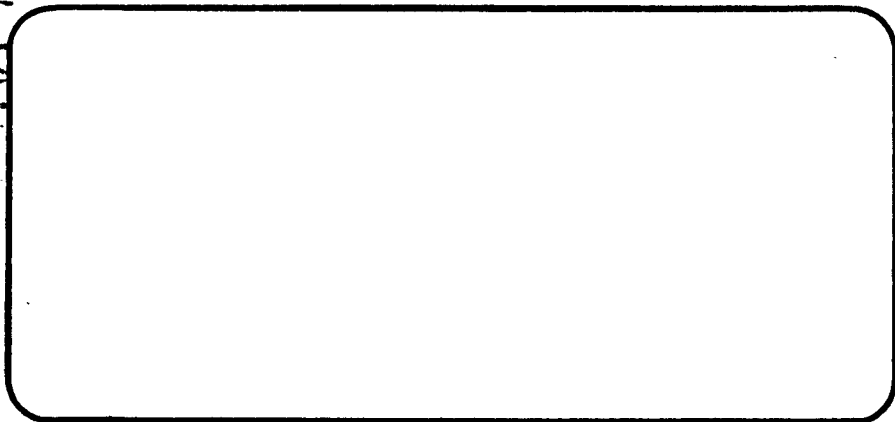
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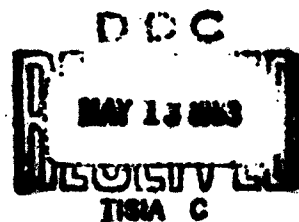
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**INTERIM D-SERIES ATLAS RELIABILITY
MEASUREMENT SYSTEM**

Prepared by

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6301-6268-RU-000

Contract No. AF 04(694)-3

29 June 1962

Prepared for

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AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Air Force Unit Post Office, Redondo Beach, California
Attention: TDC**

Prepared for
HQ BALLISTIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND, USAF
Under Contract AF 04(694)-3

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ABSTRACT

This report describes ^{1. described} an interim system for measurement of the reliability of the D-Series Atlas weapon system. Operational site and PMR Category III data are used for calculation of Reliability Trend Indices to the subsystem level in the standby, count-down and flight modes. A method for calculating Apparent Alert Readiness Probability from the same data is given. Data sources are identified and qualified, and data collection and processing methods are discussed. Sample exercises based on post-Golden Ram data are contained in Secret Addendum A, STL 6301-6269-RZ-000, of this report.

CONTENTS

	Page
1. INTRODUCTION	1
2. SUMMARY	2
3. QUALIFICATIONS AND LIMITATIONS	3
4. DISCUSSION	5
4.1 Data System	5
4.1.1 Data Sources	5
4.1.2 Reduction and Analysis	9
4.2 Application of the System	11
4.2.1 Present System	11
4.2.2 Proposed System	16
4.3 Models and Equations	20
4.3.1 Models	20
4.3.2 Qualifications of the Interim Models	31
5. CONCLUSIONS AND RECOMMENDATIONS	35
5.1 Conclusions	35
5.2 Recommendations	36
6. DEFINITIONS AND SYMBOLS	37
6.1 Definitions	37
6.2 Symbols	38

ILLUSTRATIONS

Figure		Page
1	DPL/Countdown Data Form	7
2	Data Analysis Form	10
3	Existing Method of Data Collection and Application	12
4	Proposed Reliability Data Gathering and Processing Flow	17
5	Format for Monthly and Accumulative Reports	19

1. INTRODUCTION

This report presents the results of an AFBSD-directed study to develop a workable reliability measurement system for the D-Series Atlas Weapon System. Specific direction is set forth in a letter from BSD dated 29 November 1961. Authority for this direction is based upon AF Contract 04(694)-3. A major proviso of the direction given was that the present Air Force data collection system was to be disturbed as little as possible. The measurement system submitted in this report is so designed. Also consistent with the cited directive, the models are carried to the subsystem level. Implementation methods are described, but further refinement is required to permit automation of data collection, processing and analysis. The study can be extended to develop equations which would give reliability to one level below the subsystem level as is being done during Category II testing for the E and F Series Atlas. However, these equations require data beyond that which are routinely available at the base. For this reason, only those equations which are consistent with currently available data are presented herein. Further discussion of the more sophisticated method is contained in STL proposal No. 1224, dated 25 May 1962.

The primary objective of this study was to devise a measurement system and supporting analytical methods which would permit continued assessment of weapon system and subsystem reliabilities in various operating modes. The development of mathematical expressions for weapon system reliability is a relatively straightforward analytical task which can be carried to virtually any level of detail; however, to be practical, the measurement system must be such that:

- a) The complexity of the equations does not exceed the computation capability of existing facilities
- b) The requirements of the equations are consistent with available data.

With these objectives in mind, and consistent with the cited direction, it became evident early in the study that absolute reliability measurement would not be a practical goal of the interim system. Instead, a direct means of obtaining a trend index of reliability which can be implemented under present data collection concepts was devised. While the Reliability Trend Index (RTI) is not an absolute measure of reliability, it will provide

valuable indications of relative reliabilities among the major subsystems and serves as a significant step toward eventual development of an absolute measure of reliability.

Recognizing that executive management responsibility for this weapon system is in the process of being transferred from AFSC to AFLC, the measurement system is presented in sufficient detail to minimize transitional difficulties which might otherwise occur.

2. SUMMARY

The method selected for the interim reliability measurement system for the D-series Atlas consists of the direct application of success/trial data. While more exact methods are mathematically feasible, they are not practical in light of the types of data presently available. As discussed in Section 4.1, available data lack time correlation; thus, failure rate deductions would be highly speculative. It is therefore considered wise to confine the measurement and expression of reliability to success/trial ratios for this interim system.

The equations are applied according to the major modes of weapon system operation (i. e., standby, countdown, and flight) since specific and different operating dynamics are associated with each mode. Standby data are gathered from maintenance records. The number of days on which failures have occurred in any subsystem (to be defined later) are noted. Further data are acquired which would indicate the number of days on which a particular subsystem was declared good. This is obtained by subtracting from the total number of days available on all launchers the days noted above, plus those days required for repair, MOCP, and scheduled downtime. These data, when inserted into the proper equations will give the Reliability Trend Indices during standby. The sources are listed in detail in Section 4.1 of this report.

To obtain data for the countdown Reliability Trend Index, records of post-Golden Ram launch countdowns are analyzed and the number of successful countdowns are noted. These are then divided by the total number of countdowns attempted to obtain the countdown Reliability Trend Index. If complete operation of a given subsystem is not demanded during a given

countdown, that countdown is rejected in calculating the countdown reliability by subsystem.

To obtain data for flight Reliability Trend Indices, all post-Golden Ram* missile flight** records are reviewed. In case of flight failure, the delinquent subsystem(s) are noted. The technique used above for obtaining the countdown Reliability Trend Index is again used to obtain the flight Reliability Trend Index.

Using available data, the Atlas D Interim Reliability Models for standby, countdown and flight have been exercised. The calculations and their results are contained in the Secret Addendum A to this report. It is to be noted that this is a sample calculation based on limited data. Its primary purpose is to demonstrate the workability of the models, and the results should not be considered as more than initial Reliability Trend Indices.

Continued application of the techniques and analyses described herein will in time provide Reliability Trend Indices at higher confidence levels. To obtain absolute reliability measurement some definite actions are required, especially with regard to data acquisition. Expansion of the models to accommodate a more precise measurement system is a fairly straightforward analytical task as discussed in STL proposal number 1224, dated 25 May 1962.

3. QUALIFICATIONS AND LIMITATIONS

The interim reliability measurement system presented herein will provide the best possible indices of reliability consistent with the types and quantity of data that are presently available. However, the system has definite limitations and must be qualified accordingly.

*Prior data are not considered valid because of the extensive configuration changes resulting from Golden Ram.

**Flights were made from VAFB.

The system presented herein provides the apparent rather than the absolute reliability of the weapon system. In other words, it does not take into account (a) the probability of calling a good system bad, (b) the probability of calling a bad system good, (c) effectiveness of repair, (d) the adequacy of test coverage, and (e) running time. Valid results in these areas would call for tests and data beyond the scope of present Category III plans. The implications of these assumptions are discussed in Section 4.3. Another factor to be considered is the accuracy of data used to compute the RTI. There is presently no method of establishing data validity.

In accordance with AFBSD direction, the interim measurement system is limited to the subsystem level. For the present, this depth is considered to be most practical. The use of a measurement system based on subordination below the subsystem level would require some refinement of reporting practices.

The amount of applicable data presently available is somewhat limited. Although the D-series Atlas has been in operational status for several years, data acquired before Golden Ram are not considered valid because of the extensive configuration changes resulting from the program. This factor further substantiates the wisdom in not exceeding the subsystem level of detail for the present.

As discussed in Section 4.1, there are certain limitations with regard to data acquisition and transmission in general. Data are routed to various locations, and no central collection point is maintained. This situation presently precludes automation of the measurement system, but can be corrected by including all squadron level reliability data in the Air Force Data Control System through provision of key punch information of all pertinent data.

In summary, the major qualifications are:

- a) It does not account for probabilities of false alarm, failure detection error, repair effectiveness, or test coverage
- b) There is no means of establishing the validity of reported data
- c) Maximum depth is at the subsystem level
- d) The amount of available, pertinent data is limited
- e) Data collection procedures require some refinement (see Section 4.2) to permit automation of the measurement system.

4. DISCUSSION

This section discusses the proposed reliability measurement system starting with a consideration of the existing data sources. Next is shown the application of the existing data system to reliability measurement. Then the proposed reliability measurement system is briefly outlined in a step by step fashion. Finally, the actual models and equations are presented and discussed. A sample exercise is given in Addendum A to this report.

4.1 Data System

4.1.1 Data Sources

4.1.1.1 For Reliability Trend Index During Standby. The first of the following lists comprises forms specified in AFM 66-1, which are the basic sources of data for the Reliability Trend Index during standby. Following that is a second list of data sources which may be used to corroborate the data in the first list, or to aid in directing the attention of the data collector to specific time periods and trouble areas.

a) List of Direct Data Sources (AFM 66-1)

- AFTO 209 Gives time assigned to delayed maintenance action and tends to summarize AFTO 210
- AFTO 210 Includes discrepancies and corrective action on nonrecoverable parts and is used to document the removal of a part
- AFTO 211 Includes discrepancies and corrective action on a recoverable part and is used to identify components by part number
- AFTO 212 Used to document Time Compliance Technical Orders (TCTO)

b) List of Corroborative Data (generally SAC originated)

- V-1 Summarizes the sorties in Emergency War Order Readiness (EWO) or out of EWO and gives day and general reason for being out of EWO
- V-14 Has similar breakdown as V-1's and can serve as a source of correlation

1-AFA-1 Gives further breakdown of V-1 information such as reason for being out of EWO, reasons for Missile Out of Commission for Parts (MOCP), unscheduled maintenance, etc.

U-82 Basically provides a time picture of weapon system at the launcher level in or out of EWO, and reason for being out and time out.

At present, the V-1, V-14 and 1-AFA-1 data are being reviewed by STL on a 20-day delay basis. All other data are available without delay. The 209-212 AFTO forms are cards which are filled out by the Chief of Maintenance at each squadron to record all maintenance actions, many of which may not be critical enough to affect the calculation of the Reliability Trend Indices. These cards will indicate the days of occurrence of malfunction in any part (which may then be assigned to the subsystem), the maintenance action taken, the length of time to complete the action, and the day on which the system was returned to operational status. Considerable engineering judgement is required in reviewing these forms to sort out the pertinent data.

4.1.1.2 For Reliability Trend Index During Countdown. The AFM 66-1 data control system contains no means for analyzing and recording reliability data from countdowns. Data are required from these exercises in order to determine the Reliability Trend Index for this mode. A countdown form (Figure 1) has been devised by STL in conjunction with SAC field personnel. It relates time during countdown to the occurrence of certain significant events. From this can be determined the contribution of each subsystem to the success or failure of the countdown. At present these forms have no official significance. The statistical summary forms developed by SACPO, Vandenberg as part of the Category III Test Program were reviewed. A modified version of the countdown statistical summary form is currently being used (unofficially) by STL as part of the means of implementing the Interim Reliability System. This form is official only during Category III testing. However, all Category II testing, maintenance exercising and inspection as previously planned have been suspended for Operation Shakedown. It is recommended that Operation Shakedown data be used for the calculation of the Reliability Trend Index during countdown, using the data format shown in Figure 1. An example of the use of this form is given in Addendum A.

Organization	Missile NR	Complex NR	Exercise—(24 Hour Clock)		Serial No.	Type Exercise
1	2	3	Start	Stop	Date	DPL Thru Commit
Launch Control Officer						<input type="checkbox"/>
Launch Operator						DPL Thru LO ₂ Complete
Launch Analyst						<input type="checkbox"/>
Recorder						Other (Exp Reverse Side)
						<input type="checkbox"/>

	1. Missile Erected Prior to Test Start?				Yes	No
	2. RV Installed?					

Event	Time (24 Hour Clock)				Malfunction/Time Incurred/Remarks (If continued on reverse indicate line number.)
	Start	Stop	Restart	Complete	
Launcher PWR On					
Erection HD and R					
Engine and APS					
LN ₂ /HE					
Hydraulics					
Flight Control					
Loop Test					
Fuel Rapid Load					
Fuel Fine Load					
LO ₂ Rapid Load					
LO ₂ Fine Load					
Commit					

Figure 1. DPL/Countdown Data Form

1.	State holds scheduled prior to start of operation.
2.	State actual holds incurred during the operation.
3.	List all OGE or missile subsystems not operative during this operation but normally required.
4.	Were any errors incurred because of inadequate technical orders? (if yes, explain)
5.	Could this operation have adequately supported a real launch attempt? (if no, explain)
6.	List all personnel errors, when each occurred and time delays resulting from these errors.
7.	List status of K-75 configuration control report.
8.	
9.	
10.	
11.	
12.	
13.	
14.	
15.	
16.	
17.	
18.	
19.	
20.	
21.	
22.	
23.	
24.	
25.	
26.	
27.	
28.	
29.	

Figure 1. DPL/Countdown Data Form (Continued)

4.1.1.3 For Reliability Trend Index During Flight. No data form has been prepared for flight since existing GD/A and SAC documentation of Category II/Category III flights is more than adequate for the interim model.

4.1.2 Reduction and Analysis

4.1.2.1 For R_s (Standby Reliability). The data from the AFTO 209-212 data series are summarized on an analysis form of the type shown in Figure 2. One of these forms is used for each launcher for the time period involved. It must be emphasized that data from all launchers for the same time period must be utilized in order to obtain a Reliability Trend Index. Use of this form for April for the first launcher of Complex A of the SMS 549 is shown in Addendum A.

4.1.2.2 For R_{cd} (Countdown Reliability). In order to obtain enough data to permit a reasonable approximation of the Reliability Trend Index during countdown, DPL's are to be analyzed as well as the very limited number of post-Golden Ram launch countdowns. In analyzing the entire weapon system program, it was concluded that the DPL is the exercise closest to the countdown capable of providing adequate data to permit statistically meaningful results. In using the DPL for countdown data, one precaution must be observed; i. e., the DPL is completed at generation of the engine start signal, whereas the actual launch countdown is continued to liftoff. Hence, DPL acquired data will not include the engine start sequence or the holddown and release actuation, and these omissions must be taken into account in the computation of the countdown Reliability Trend Index. As noted earlier, the AFM 66-1 data collection system contains no provision for countdown or DPL reporting except for maintenance records. In consequence, the form in Figure 1 was developed to supply these data. It has been devised so that the easily discernible significant events may be noted. These are events which may be noted from the Launch Control Console, the Launch Operation Panels, and the Launch Analyst Panel. These events may be related readily to the major subsystems. It is recommended that this form be used to implement the interim data collection system.

4.1.2.3 For R_f (Flight Reliability). The information contained in the flight test summary reports prepared by GD/A and SAC is sufficiently summarized to be used directly in flight/reliability calculations.

Missile Serial No. _____

Date: _____

<u>Subsystem</u>	<u>N_i</u>	<u>D_i</u>
Electrical		
Flight Control		
Guidance		
Hydraulics		
PLS		
Propulsion		
Pneumatic		
R/V		
Pyrotechnics		
Launcher		
LN ₂ /HE		
Direct Support RPIE		
Ground Handling Equipment		
Communications		
Launch Control and Checkout		
Airframe		

Figure 2. Data Analysis Form

4.2 Application of the System

4.2.1 Present System

This section describes the actual application of the interim reliability measurement system. To demonstrate the workability of the system, sample exercises were conducted as a part of this study. In exercising the data collection, data reduction, correlation and presentation system, the general procedure followed the logic flow diagram of Figure 3. The calculations of Reliability Trend Indices using these data are contained in Addendum A.

Referring to Figure 3, the following preliminary steps must be taken in order to obtain reduced data for use in the reliability calculations.

- Step 1 The DPL form, the AFTO No. 209, 210, 211, 212, T and E tapes, APCHE tapes, guidance charts, guidance computer tapes—the AF-14 1AFA-1, the U-82, the V-1 data, the training flight data, were all reviewed for the purpose of establishing the missile emplacement "out of EWO" time.
- Step 2 After culling through the above mentioned reports, the AFTO Nos. 209, 210, 211, and V-1 reports formed the main basis from which the "out of EWO" time was derived. The DPL forms were also used. These are covered in Steps 11 and 12.
- Step 3 The V-1 reports at VAFB are always used, however due to SAC policy they must be 20 days old before STL can review them. From the V-1 reports (which are TWX's dispatched from squadron control center anytime there is a change in missile emplacement EWO status, according to parameters established by SAC policy - Example: if it takes a half hour or less to fix, don't report it). Time bar graphs for each emplacement are plotted from the V-1 reports and these are used as a source of correlation against maintenance data derived elsewhere.
- Step 4 In most cases where the AFTO No. 209 is used, it is not necessary to use 210 or 211. The 209 is a chronological summary of the 210's and 211's. On occasion the 210's and 211's will be sifted - these yield maintenance information at a subordinate hardware level, but might possibly clarify an indecisive point. This is done by hand and usually a two man team.

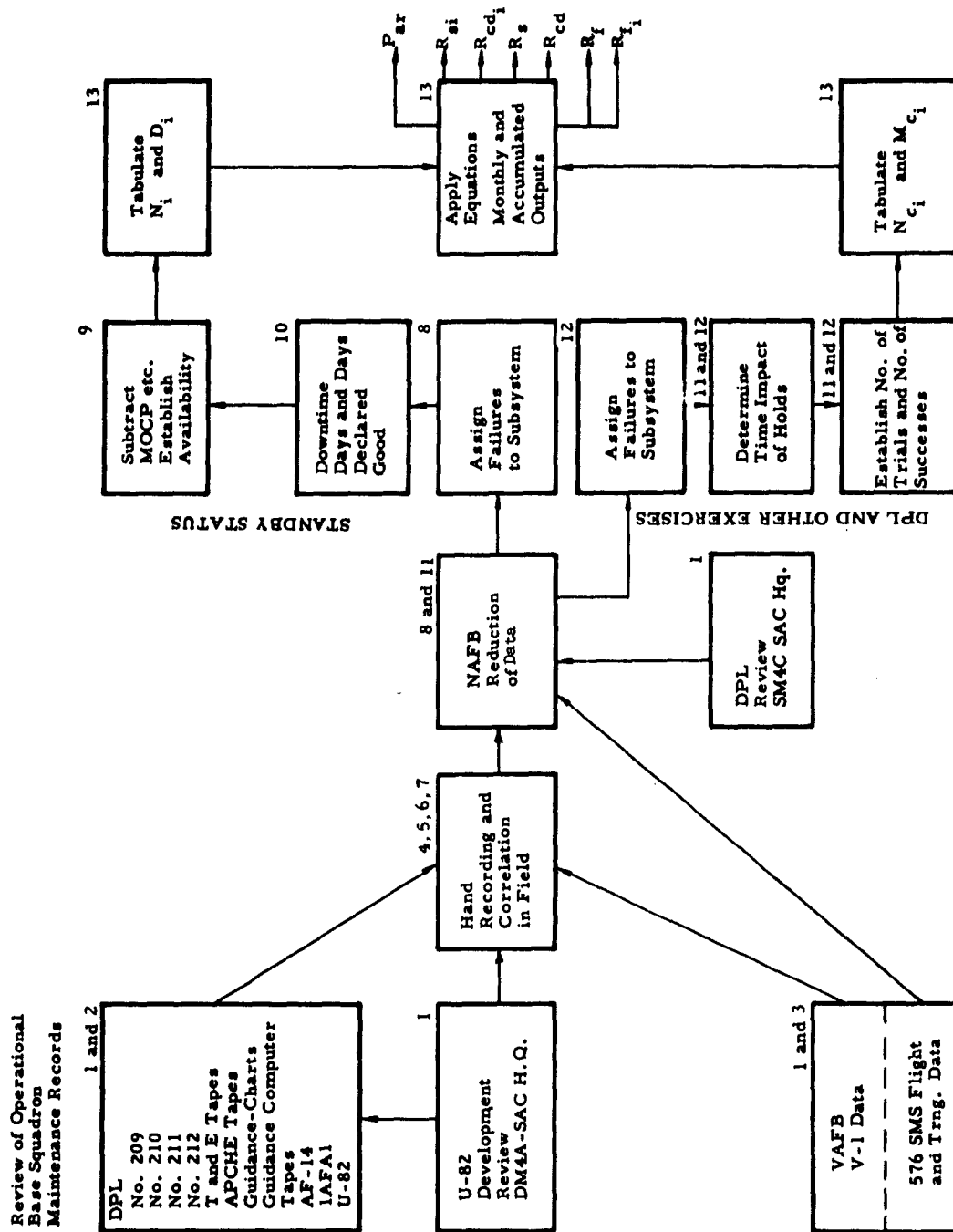


Figure 3. Existing Method of Data Collection and Application

- Step 5** The maintenance data derived from the AFTO No. 209 forms covered all the functional subsystems with the following exceptions: Pyrotechnics, re-entry vehicle, communications (incomplete). The data on the 209 forms were considered on the basis of whether the maintenance problem reported occurred at such a time and was serious enough in nature to have caused the missile emplacement to go out of EWO—this was recorded in a format similar to Figure 2. Due to a shortage of qualified personnel, the 209 forms relating to guidance problems were copied and returned to NAFB for analysis there and subsequently these were handled in the same manner as the other information on the Figure 2 forms.
- Step 6** The number of different days on which a missile emplacement went off EWO during a scanning period (this period is usually 30 days) and the duration of downdays that the problem incurred would be reported against the offending subsystem. One or more faults in the same day, would be regarded as one fault and attributed to the first responsible subsystem. To resolve any question as to which is the offending subsystem the T.O. 21-SM65D-06-1 and -2 were used.
- Step 7** If it appears that either individual or cumulative maintenance problems exceed the downtime allowed by policy to still maintain EWO status, then the V-1 time bars are used as a source of correlation.
- Step 8** This Figure 2 data is then returned to NAFB from all squadrons in the Series D Atlas weapon system where on a subsystem basis all the days were summed on which the missile emplacement went out of EWO.
- Step 9** On a subsystem basis the MOCP or TCTO days, etc., is subtracted from the number of down days to give an accurate downtime as a result of a specific subsystem malfunction.
- Step 10** On a subsystem basis, the number of missile days available is computed by subtracting the sum of the scheduled and the unscheduled down days from the number of days in the scanning period.
- Step 11** On a subsystem basis (and using the time criterion establishing by SAC for a successful DPL) the number of trials and the number of successes are determined.
- Step 12** The number of successful subsystem completions during a failed DPL are determined (this is accomplished by a knowledge of the various subsystem times to completion during a normal DPL).

Step 13 The results of Steps 8 through 12 are forwarded for application of the equations. The final outputs are the reliability of each subsystem during standby, during countdown (DPL), the reliability of all subsystems during standby and during countdown (DPL).

SAC V-1 data for the Atlas D fleet covering the period January through March 1962 were obtained and analyzed for possible application to the measurement system. A substantial screening effort was required to sort out usable data. April data were taken from AFTO 209 forms at Warren AFB and AFTO forms 209, 210, and 211 at Offutt AFB. In the study of these forms the following observations were made:

The accuracy of the 66-1 data appeared to be somewhat biased because many items which were reported as detected in April had been carried forward to May with no solution being reported in April. Consequently, no record of these detections or downtimes were included in April reports. Other items were reported as having failed and as repaired two or three times during the month of April. In some instances these were apparently repetitions of the same problem and were erroneously reported as failures or as repaired. Another problem encountered was that the data are not explicit with regard to effect on EWO status. Such items as guidance receivers or transmitters might or might not take the site out EWO depending upon their degree of misalignment. In the latter example, the weapon system was given the benefit of the doubt and alignment problems were not reported as out-of-EWO failures. A problem also appeared with items having been reported out for maintenance in March and reported repaired near the middle of April. These were recorded as being out of EWO until the time repaired. The anomalies cited above could cause gross distortion of the Reliability Trend Index.

Time bar charts were drawn from the V-1 reports for April showing the reported in or out of EWO status as reported to SAC through the squadron job controller. Next, the V-1 data were correlated with the AFTO data and further correlation was obtained through direct contact with responsible maintenance personnel at the squadron or wing levels. Data for this correlation effort were not available at any central location, but had to be extracted from the maintenance and EWO status records at each site. Consequently, a study was made of current data transmission practices in order to establish the feasibility of a fully computerized program for data collection and reduction. It was found that under the existing method certain subsystem data are not transmitted to SBAMA. The deficient areas are:

- a) Data for the communication subsystem. All of this data is not routed through squadron records but on a problem selective basis goes through the base Statistical Services, then to Memphis, Tennessee, and ultimately to Rome AMA. Some selected data are transmitted to SBAMA.
- b) Data from the pyrotechnic subsystem. Pyrotechnics cannot be dynamically tested at operational sites, except at VAFB in conjunction with actual flights. Some information regarding the reliability of this subsystem is apparently available through OAMA at Ogden, Utah. However, it appears at present that considerable more work is required on this subsystem to obtain complete data.
- c) The warhead and re-entry vehicle subsystem. Data are being recorded at the squadron level and are being transmitted to SBAMA. However, this is a very small portion of the total available data because many of the problem areas develop at the S and I Building and these data are sent to the San Antonio Air Materiel Area. Thus, many faults occurring in re-entry vehicle and warhead appear to be recorded only at SAAMA and are not transmitted on a regular basis to SBAMA.

Pertinent to a computerized program to select the required data from that submitted by the operational bases, the following basic data must be extracted from the punched cards arriving at SBAMA:

AFTO Nos. 210, 211, 212

Work Unit Code	Base, BSAC	Report Number
Date	Weapon System	Action Taken Code
Missile Number	Site Work	Part or Component
Part Number	Center Code	Serial Number

Almost immediately upon the turnover of the Atlas D weapon system to SAC, Operation Shakedown was established. This will create a considerable amount of data on an accelerated basis insofar as the countdown is concerned, and will permit calculation of Reliability Trend Indices of high confidence for the countdown mode if the data are used.

Data for calculation of the Reliability Trend Index for flight will be limited to the presently planned Category III flights from VAFB. Thus the Reliability Trend Index will be based on a limited population.

4.2.2 Proposed System

The logic flow diagram shown in Figure 4 is the proposed automated data reduction system. Listed below is an explanation of what is accomplished at each numbered step.

- Step 1 SBAMA receives IBM cards or card images on magnetic tape. At present data is not available for the pyrotechnics, R/V and communication subsystems because other AMA's have prime responsibility for these subsystems. Negotiations are presently being held to arrange for these data to be shipped to SBAMA from these AMA's.
- Step 2 Place all data on magnetic in card image format (22,000 card images per tape).
- Step 3 Delete all data that is not necessary, that is items that would not take the missile out of EWO. The "Action Taken Code" will be used for this purpose. An example of this is Code A which states, "This code will be applied only if it is determined that a deficiency reported by the air crew or maintenance personnel does not exist or cannot be duplicated."*

* T.O. 21-SM65D-06-1 and -2, Technical Manual, Work Unit Code Manual, USAF Model SM65D, Ballistic Missiles, dated 1 October 1961, p. vii.

- Step 4 Correlate AFTO 210, 211, and 212 forms for the same problem. This is done by using the Report Number (item G on 210 and 211 forms) and the Original Report Number (Item F on 210 and 211 forms).
- Steps 5 and 6 The next two steps are done to arrange the data by squadrons and then by sites per squadron. This is done by using the Work Center Code, Item 4 on the 210 and 211 forms, which identifies squadron and site by code.
- Steps 7 and 8 These steps are used to group the data by site peculiar and missile peculiar subsystems. This is done by using the Work Unit Code, Item 7 on the 210 and 211 forms. The Work Unit Code consists of six numerical and alphabetical characters and is used to identify the system, subsystem and component that was worked on and the work that was done (action taken).
- Step 9 Check Work Unit Code against component number to verify that the correct Work Unit Code was used.
- Step 10 Calculate failures for each subsystem. Since only those items that would cause an out of EWO condition are listed, the other data being eliminated in Step 3, all that is required is to sum the failures (inputs) for all subsystems per site and then sum for all sites.
- Step 11 The calculation of "down days" is a little more complicated. First all the dates on the V-1 forms must be converted to a three digit number so they can be added and subtracted. Sum all days per subsystem that caused the missile to be out of EWO, then total these for all sites.
- Step 12 Calculate the "good days" per subsystem by subtracting the "down days" from the available days, the available days being the total days in the time period under consideration. This is usually one month.
- Step 13 Apply equations.
- Step 14 Publish monthly and cumulative status periodically in the format shown in Figure 5.

(See sample exercise in Addendum A)

RELIABILITY MATRIX OUTPUT *

Subsystems	R_{s_i}	λ_{s_i}	R_{cd_i}	R_{f_i}	$R_{cd_i} R_{f_i}$
Electrical					
Flight Control					
Guidance { Non-Redundant Redundant					
Hydraulic					
Propellant Loading System					
Propulsion					
Pneumatic					
R/V					
Pyrotechnics					
Launcher					
LN ₂ /HE					
Direct Support RPIE					
Ground Handling Equipment					
Communications					
Launch Control and C/O					
Airframe					
$R'_s = R_g \pi R_{s_i}$					
$R_s = \pi R_{s_i}$					
$\lambda_s = \sum \lambda_{s_i}$					
$R_{cd} = \pi R_{cd_i}$					
$R_f = \pi R_{f_i}$					
$R_{cd} R_f = \pi R_{f_i} R_{cd_i}$					
$P_{ar} = \frac{1}{1 + \lambda_s T_r}$; $T_r = \text{--- days}$					

* See page 38 for definitions of symbols.

Figure 5. Format for Monthly and Accumulative Reports

4.3 Models and Equations

4.3.1 Models

Starting with the elementary method of success/trial ratio, it is possible to express reliability in various mathematical forms. By introducing time correlation, event probabilities can be expressed as failure rates, and more sophisticated reliability expressions are thus developed. For this interim model, however, the conventional success/trial method is the most practical, primarily because time-correlated data are not available. Because of the unique operating stresses associated with each major mode of weapon system operation, the standby, countdown, and flight modes each have to be considered separately in the measurement system.

4.3.1.1 Flight or Countdown. The subsystem is determined to which one can attribute the failure of either a flight or a countdown. By failure is meant preventing the countdown or flight from reaching the prescribed goal. In either case, the Reliability Trend Index is calculated in the same manner. If "i" indicates the subsystem and "j" indicates the mode (either countdown or flight) then

$$R_{ij} = 1 - \left(\frac{N_{ij}}{M_j} \right) \quad (1)$$

where N_{ij} are the number of failed exercises (j) attributable to the i^{th} subsystem and M_j is the total number of the j^{th} exercise. In the case of countdown, any subsystem malfunction which prohibits attainment of lift-off within a prescribed interval is considered to have caused the failure of the countdown and the subsystem involved is so charged. In the case of flight, any subsystem malfunction which causes the flight to deviate beyond 3 CEP from the target is considered as having caused a failure of the flight and the subsystem involved is so charged.

Assuming the independence of the subsystems, it is possible to obtain a Reliability Trend Index, which is given by the following equation

$$R_j = \prod_{i=1}^k R_{ij} \quad (2)$$

alternately

$$R'_j = R'_g \prod_{i=1}^{k-1} R_{ij} \quad (3)$$

where

$$R'_g = 1 - \left(\frac{N_g}{M_g} \right)^n \quad (4)$$

for ground guidance.

N_g = Number of failed ground guidance exercises

M_g = Total number of ground guidance exercises

n = Number of ground guidance sites per squadron

where R_j is the weapon system Reliability Trend Index during either count-down or flight and "k" is the total number of subsystems involved. π indicates the product rule.

4.3.1.2 Derivation of the Equations for Standby Reliability. Obtaining a Reliability Trend Index for the standby phase is conceptually somewhat more difficult and remote than for the other two phases. In the previous cases, there were specifically defined exercises with specific goals. During standby, no one specific exercise exists for which success and failure are easily definable. A definition may be obtained by assuming that the standby period is divided into a series of 24-hour periods and that failure and success are defined in terms of the completion of a day with either malfunction indication or no malfunction indication. Since this day is repeated continuously it may be considered a test, and by collecting the number of days on which a malfunction has been indicated in a specific subsystem, it is possible to obtain a Reliability Trend Index for that subsystem. Thus, if N_i indicates the days throughout the whole force and during the time period involved on which a specific subsystem has been noted as having failed (either through monitoring, special inspections,

testing, etc.), and if D_i is defined as the sum of these days during the time period in question on which the subsystem has been declared good by the monitoring system, special inspection, testing, etc., then the Reliability Trend Index of the i^{th} subsystem during standby is given

$$R_{s_i} = 1 - \frac{N_i}{N_i + D_i} \quad (5)$$

This heuristic approach may be placed on a rigorous basis and the relationship of this formula to time and the failure rate distribution may be shown by the following considerations.

Consider a basic time interval of fixed length τ . The probability $P_s[\tau/G]$ of surviving the time τ , given that the equipment enters the interval nonfailed, is called the reliability $R_s[\tau]$ of the equipment for a time τ . That is

$$P_s[\tau/G] \triangleq R_s[\tau] \quad (6)$$

Let there be a total of M intervals of length τ in a greater interval of length T , at the commencement of which the equipment is nonfailed. Let there be N intervals out of the M intervals of length τ in the interval T , at the commencement of which the equipment is nonfailed, but during which one or more failures occur. In general

$$M\tau \leq T \quad (7)$$

$$M = N + D \quad (8)$$

N = Number of intervals of length τ during which one or more failures occur, given that the equipment was nonfailed at the start of the interval.

D = Number of intervals of length τ which the equipment survives, given that the equipment was nonfailed at the start of the interval.

The "less than" sign arises from the fact that during some of the intervals of length τ in T the equipment will be down at the start of the interval. All such τ must be eliminated from the calculation, hence the inequality.

The probability $P[M, N]$ of obtaining a succession of exactly N "bad" intervals out of a total of M intervals is given by

$$P[M, N] = \frac{M!}{N!(M-N)!} (1 - R_s[\tau])^N R_s[\tau]^{M-N} \quad (9)$$

where it is explicitly assumed that the probability of calling a nonfailed system bad is zero, the probability of calling a failed system good is zero, and the test coverage is complete.

For convenience, define

$$L \triangleq \log P[M, N] \quad (10)$$

Then the most likely value of $R_s[\tau]$ is given by setting

$$\frac{\partial L}{\partial R_s[\tau]} = 0 \quad (11)$$

and solving the resulting equation for $R_s[\tau]$ in terms of M and N

$$\frac{\partial L}{\partial R_s[\tau]} = \frac{M - N - M R_s[\tau]}{(1 - R_s[\tau]) R_s[\tau]} = 0 \quad (12)$$

since

$$0 \leq R_s[\tau] \leq 1 \quad (13)$$

it follows that (12) can be zero only if the numerator is zero. Hence

$$R_s[\tau] = 1 - \frac{N}{M} = 1 - \frac{N}{D + N} \quad (14)$$

If the subscript i denotes a particular subsystem

$$R_{s_i}[\tau] = 1 - \frac{N_i}{D_i + N_i} \quad (15)$$

if an exponential failure distribution is assumed

$$R_{s_i}[\tau] = e^{-\lambda_{s_i} \tau} \quad (16)$$

Hence

$$\begin{aligned} \lambda_{s_i} &= -\frac{1}{\tau} \ln R_{s_i}[\tau] \\ &= -\frac{1}{\tau} \ln \left(1 - \frac{N_i}{N_i + D_i} \right) \end{aligned} \quad (17)$$

Further, for an arbitrary time period of length T_s

$$R_{s_i}[T_s] = \left(e^{-\lambda_{s_i} \tau} \right)^{T_s/\tau} \quad (18a)$$

$$= \left(1 - \frac{N_i}{N_i + D_i} \right)^{T_s/\tau} \quad (18b)$$

Further, if all subsystems are independent, then the reliability of the total system becomes for k subsystems

$$R_s[\tau] = \prod_{i=1}^k R_{s_i}[\tau] \quad (19)$$

It must be indicated that this method of calculation is specifically related to the hardware reliability and has no direct bearing on the in-commission rate, since the definition specifically omits repair days, MOCP days, etc. The malfunction days (N_i) and the days declared good (D_i) are counted over the entire force and not for one launcher; hence, the total launcher days will be many times greater than the total calendar days and will present a sizeable statistical sample.

The Reliability Trend Indices assume that the means of discovering the malfunctions in terms of monitoring, checkouts, special inspections, etc., are both all inclusive and completely valid; nonetheless, they will prove useful in determining reliability trends and identifying problem areas.

The reliability models are developed by applying the previous equations to the logic and subsystems concerned in accordance with the mode of operation to be considered. Thus, the equations become a mathematical description, or model, of a particular system under specific conditions. For the interim model, the equations are applied to the subsystem level (e.g., autopilot, guidance, R/V, propulsion, propellant loading system, communications, etc.). The assumption is made that the product rule is valid, i.e., that the weapon system reliability is the product of the subsystem reliabilities. At this level, the assumption is reasonable, since any major subsystem failure would generally result in mission failure, whether the mode be standby, countdown, or flight. One major exception is the guidance subsystem, where more than one ground guidance station is available to the launch complex. This "handover capability" as it is termed, makes the ground guidance centers redundant with respect to the launch complexes and must be accounted for, provided that no penalty is exacted for the delayed reaction time which is incurred by handover. This redundancy is handled as indicated in Equations 22, 23, and 24 below. On the other hand, if delayed reaction time is considered to be a failure, then the guidance subsystem is handled in exactly the same fashion as the other subsystems, i.e. by Equations (20) and (21).

a. Reliability Trend Index During Standby

- 1) Reliability Trend Index of the i^{th} subsystem for a time τ during standby (maximum likelihood estimate)

$$R_{si}[\tau] = 1 - \frac{N_i}{N_i + D_i} \quad (20)$$

τ = Least reporting time period in an arbitrary time period of length T_s : in all cases checked to date τ may be taken as one day.

N_i = Number of time periods of length τ in an arbitrary time period of length T_s in which the i th subsystem experiences one or more failures; given that it was non-failed at the start of the time period

D_i = Number of reporting time periods during the arbitrary time period T_s that the i th subsystem was reported nonfailed for the entire time period τ .

- 2) Reliability Trend Index of one missile/launch complex for a time τ during standby without guidance handover capability

$$R_s[\tau] = \prod_{i=1}^k R_{si}[\tau] \quad (21)$$

k = Number of subsystems

- 3) Reliability Trend Index of one missile/launch complex for a basic time period τ during standby with guidance handover capability to any of "n" ground guidance centers, and without penalty for delayed reaction

$$R_s'[\tau] = R_g'[\tau] \prod_{i=1}^{k-1} R_{si}[\tau] \quad (22)$$

where,

$$R_g'[\tau] = 1 - (1 - R_g[\tau])^n \quad (23)$$

and,

$$R_g[\tau] = 1 - \frac{N_g}{N_g + D_g} \quad (24)$$

$R_g[\tau]$ = Guidance System Reliability Trend Index for the time period τ

N_g = Number of reporting periods of length τ during an arbitrary time period of length T_s that a typical guidance system experiences one or more failures; given that the guidance system was non-failed at the start of the reporting time period τ

D_g = Number of reporting period that the same guidance system was reported nonfailed for the entire period τ during the time period T_s

- 4) Reliability Trend Index for an arbitrary time period T_s is the probability of surviving the entire interval T_s without a failure occurrence, in contrast to the probability of success in any single sample of τ , which is given by Equation (1). (For example $\tau = 1$ day, $T_s = 90$ days.)

(a) By subsystem

$$R_{si} [T_s] = (R_{si} [\tau])^{T_s/\tau} = \left(1 - \frac{N_i}{N_i + D_i}\right)^{T_s/\tau} \quad (25)$$

(b) Total system without guidance handover capability

$$R_s [T_s] = \prod_{i=1}^k R_{si} [T_s] = \prod_{i=1}^k \left(1 - \frac{N_i}{N_i + D_i}\right)^{T_s/\tau} \quad (26)$$

- 5) Apparent subsystem failure rates during standby

$$\lambda_{si} = -\frac{1}{\tau} \ln \left(1 - \frac{N_i}{N_i + D_i}\right) \quad (27)$$

λ_{si} = Apparent subsystem failure rate in failures per unit time assuming an exponential apparent-failure distribution

τ = Basic time reporting period associated with the counts N_i and D_i

N_i, D_i = [(See subparagraph 1) above]

- 6) Total apparent failure rate λ_s per missile/launch complex during standby

$$\lambda_s = \sum_{i=1}^k \lambda_{si} \quad (28)$$

λ_s = Total missile/launch complex apparent failure rate

k = Total number of subsystems in one missile/launch complex

b. Apparent Alert Readiness (P_{ar}) of a Missile/Launch Complex

Alert readiness is the probability that a missile/launch complex will be capable of responding to an execution directive received at an arbitrary, unknown point in time. It is therefore, a measure of the average reliability of a missile/launch complex during the standby condition given by

$$P_{ar} = \frac{(1/\lambda_s)}{(1/\lambda_s + \bar{T}_r)} \quad (29)$$

$$\bar{T}_r = \frac{1}{n} \sum_{i=1}^n T_{r_i} \quad (30)$$

λ_s = Total apparent failure rate per missile/launch complex

\bar{T}_r = Mean missile/launch complex reported downtime per apparent failure

T_{r_i} = Duration of reported downtime on i^{th} occurrence

n = Number of reported downtimes

4.3.1.3 Launch Countdown Reliability Trend Index

- 1) Launch Countdown Reliability Trend Index by subsystem from all data sources.

$$R_{cd_i} = 1 - \frac{N_{c_i}}{M_{c_i}} \quad (31)$$

$$R_{cd} [G] = \frac{k}{n} \sum_{i=1}^n R_{cd_i} \quad (32)$$

N_{c_i} = Total number of failures of the i^{th} subsystems during countdowns

M_{c_i} = Total number of countdowns during which i^{th} subsystem was exercised

2) Overall Countdown Reliability Trend Index

$$P_{cd} [G, t] = R_{cd} [G] P_{cd} [t/G] \quad (33)$$

$$R_{cd} [G] = \frac{S_c}{T_c} \quad (34)$$

$$P_{cd} [t/G] = 1 - e^{-\frac{t-t_r}{t_c}} \quad ; t > t_r \quad (35a)$$

$$P_{cd} [t/G] \approx 0; t \leq t_r \quad (35b)$$

$P_{cd} [G, t]$ = Probability of completing a launch countdown successfully in a time "t" or less

$R_{cd} [G]$ = Probability of completing a launch countdown successfully without regard for reaction time.

$P_{cd} [t/G]$ = Probability of completing a launch countdown in time "t" or less given that it is a successful countdown

S_c = Number of launch countdown successes

T_c = Number of launch countdown trials

t_r = Minimum reaction time

t_c = Reaction time constant

To determine t_r and t_c , first rank the times to complete successful countdowns in order of increasing time,

$$t_{\min} = t_n \leq t_{n-1} \leq t_{n-2} \dots \leq t_2 \leq t_1 = t_{\max} \quad (36)$$

Associate a number P_i with each "t" as follows

$$\begin{aligned} (t_{\max} = t_n; P_n = \frac{n}{n+1}); & (t_{n-1}; P_{n-1} = \frac{n-1}{n+1}); \\ (t_{n-2}; P_{n-2} = \frac{n-2}{n+2}) & : (t_2; P_2 = \frac{2}{n+1}); \\ (t_1 = t_{\min}; P_1 = \frac{1}{n+1}) & \end{aligned} \quad (37)$$

It can then be shown that a least mean squared estimate of the values for t_r and t_c are given by

$$\frac{1}{t_c} = - \frac{\left(\sum_{j=1}^n \ln P_j \right) \left(\sum_{j=1}^n t_j \right) - n \sum_{j=1}^n t_j \ln P_j}{\left(\sum_{j=1}^n t_j \right)^2 - n \sum_{j=1}^n t_j^2} \quad (38)$$

$$\frac{t_r}{t_c} = \frac{\left(\sum_{j=1}^n t_j \right) \left(\sum_{j=1}^n t_j \ln P_j \right) - \left(\sum_{j=1}^n \ln P_j \right) \left(\sum_{j=1}^n t_j^2 \right)}{\left(\sum_{j=1}^n t_j \right)^2 - n \sum_{j=1}^n t_j^2} \quad (39)$$

4.3.1.4 Flight Reliability Trend Index

1) Total Flight Reliability Trend Index from flight tests

$$R_f = \frac{S_f}{T_f} \quad (40)$$

S_f = Total successful flights

T_f = Total flights

Place confidence limits on Equation (40) using standard tables.

2) Flight Reliability Trend Index by subsystem

$$R_f = \prod_{i=1}^k R_{f_i} \quad (41)$$

$$R_{f_i} = 1 - \frac{N_{f_i}}{M_{f_i}} \quad (42)$$

N_{f_i} = total flights of the i^{th} subsystem on which it failed

M_{f_i} = total flights during which the i^{th} subsystem was exercised.

4.3.2 Qualifications of the Interim Models

4.3.2.1 Alert Readiness for a Continuous Monitoring Policy. It may be shown¹ that a system which is governed by exponential distributions for failure, perfect repair, failure detection and false alarm exhibits an alert readiness given by the equation.

$$P_{ar} = \frac{1}{1 + \frac{\lambda_d}{e} + \frac{\lambda_d + \lambda_u + a_c}{\mu_c} + \frac{\lambda_u}{a_c + \lambda_d} \left(1 + \frac{\lambda_d}{e}\right)} \quad (43)$$

where

λ_d = Failure rate associated with failures that are "detectable in principle"

λ_u = Failure rate associated with failures that are "inherently undetectable in principle"

a_c = False alarm rate associated with those characteristics of the equipment which are continuously monitored.

μ_c = Rate of restoration of equipment to the non-failed state, assuming that failures of either class, and false alarms, are treated in an equivalent manner (remove and replace)

e = Rate of detection of true failures of the "detectable in principle" class

By "detectable in principle" it is meant that the failure belongs to the class of observable failures. By "inherently undetectable in principle" it is meant that failures of this class are unobserved by the nature of the monitoring used. Examples of this class of failure are pyrotechnics, re-entry vehicle fusing and arming, and engine firing.

¹A. J. Monroe. "Missile/Launch Complex-As-A-Unit Models for the Determination of Weapon System Capability," STL report number 6301-6237-TU-000, 4 May 1962, Pages 53-60.

The equation for alert readiness used in the interim model is derived from Equation (43) by means of the following simplifying assumptions:

$$\begin{aligned}\lambda_u &= 0 \\ \alpha_c &= 0 \\ \frac{1}{e} &= 0\end{aligned}\tag{44}$$

Hence, Equation (43) reduces to

$$P_{ar} = \frac{1}{1 + \frac{\lambda_d}{\mu_c}}\tag{45}$$

The total effect of these simplifying assumptions on the apparent value of alert readiness is unknown. However, the qualitative effect is easily determined by inspection of Equation (43). The parameters λ_u and α_c have the same order of effect as λ_d . The value of P_{ar} varies linearly with e and μ_c to first order, hence these parameters have a greater potential influence than any of the remaining parameters.

In the derivation of Equation (43) it was assumed that at least one characteristic of every remove-and-replace module was monitored. For those equipments which are not monitored at all, Equation (43) reduces to zero, since in this case

$$\begin{aligned}\alpha_c &= \mu_c = 0 \\ \frac{\lambda_u}{\lambda_d} &\rightarrow \infty\end{aligned}\tag{46}$$

Accordingly, actual alert readiness may differ markedly from apparent alert readiness.

4.3.2.2 Reliability. Reliability is traditionally defined as the conditional probability that an equipment will survive a specified time, given that it is initially nonfailed. A measure of greater significance for the Atlas weapon system is the total probability

$$P[G, T_s] = P[G]P[T_s/G] \quad (47)$$

$P[G]$ = Probability that the equipment is good at entrance to T_s

$P[T_s/G]$ = Probability that the equipment survives T_s , given that it was good at entrance to T_s

For a system which is continuously monitored, and for which the reliability is desired at a random point in time, $\tau + T_s$

$$P[G, \tau \leq t \leq \tau + T_s] = \frac{e^{-\left(\lambda_u + \lambda_s\right) T_s}}{1 + \frac{\lambda_d}{e} + \frac{\lambda_d + \lambda_u + a_c}{\mu_c} + \frac{\lambda_u}{a_c + \lambda_d} \left(1 + \frac{\lambda_d}{e}\right)} \quad (48)$$

The same remarks apply to this equation as applied to alert readiness.

If a system is subjected to a periodic maintenance policy on certain items, then the reliability of each of those items is given by²

$$P[G, T_s] = \frac{\mu_1 E P_{d_{T_s}} P_{u_{T_s}} \left\{ 1 - P_{d_T} (1 - a) \right\}}{\left\{ 1 - P_{d_T} P_{u_T} (1 - a) \right\} \left\{ 1 - P_{d_T} (1 - a) + P_{d_{T_{c_1}}} P_{d_{T_s}} (1 - \mu_2) (E - a) \right\}} \quad (49)$$

where;

$$P_{d_T} = P_{d_{T_{c_1}}} P_{d_{T_{c_2}}} P_{d_{T_s}} P_{d_{T_r}} P_{u_{T_{c_1}}} P_{u_{T_{c_2}}} P_{u_{T_s}} P_{u_{T_r}} \quad (50)$$

where each of the P_i in Equation (50) is given by (51)

$$P_i = \frac{\Delta}{e^{-\left(\lambda_i\right) T_i}}$$

² Ibid. page 46, Equation 119

for the exponential failure distribution, where

- μ_1 = Probability that a repaired or replaced item is nonfailed
- μ_2 = Probability that a repaired or replaced item contains a failure of the "inherently detectable in principle" class
- E = Probability that a failure of the "inherently detectable in principle" class will be caught during checkout
- α = Probability that nonfailed items will be rejected during checkout (false alarm probability)
- $P_{d_{T_{c_1}}}$ = Probability that the inherently detectable class of items will survive the portion of checkout prior to test decision
- $P_{d_{T_{c_2}}}$ = Probability that the inherently detectable class of items will survive the portion of checkout remaining after the test decision is made, given that they pass the test (no false alarm).
- $P_{u_{T_{c_1}}}$ = Probability that the inherently undetectable class of items will survive the portion of checkout prior to test decision
- $P_{u_{T_{c_2}}}$ = Probability that the inherently undetectable class of items will survive the portion of checkout remaining after the test decision is made, given that they are not false alarmed.
- $P_{d_{T_s}}$ = Probability that the inherently detectable class of items will survive the scheduled alert interval T_s
- $P_{u_{T_s}}$ = Probability that the inherently undetectable class of items will survive the scheduled alert interval T_s
- $P_{d_{T_r}}$ = Probability that the detectable class of items will survive the time period T_r
- $P_{u_{T_r}}$ = Probability that the undetectable class of items will survive the time period T_r

Note that this expression exhibits a first order variation with μ_1 , E , $P_{d_{T_s}}$ and $P_{u_{T_s}}$. In short, these analogs of μ_c , e , λ_d , and λ_u have the same relative effect on the system reliability calculations.

Whether a system is monitored continuously or checked out periodically, there will be a first order dependence upon the quality of the test (E, e) and on test coverage (λ_u, P_u). The extent to which apparent reliability and apparent alert readiness should be degraded to obtain the true reliability and the true readiness is not known. Steps should be taken to obtain numerical estimates of E, e, λ_u , and P_u in order that the degradation may be calculated.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The interim reliability measurement system for the D-Series Atlas described herein provides a means of assessing reliability trends utilizing currently available data sources. It provides Reliability Trend Indices to the subsystem level for the principal operating modes of standby, count-down, and flight as well as the Apparent Alert Readiness Probability for the weapon system.

A comprehensive reliability measurement system, when combined with proper engineering evaluation, will prove to be a valuable aid in discerning the significance of problems reported by the using command. Efficient allocation of the engineering effort toward the solution of such problems will be possible, thus leading to an improvement of the weapon capability.

This reliability measurement system will provide the necessary factors for calculation of weapon system capability, subject to the limitations indicated below in the event that such a calculation is required.

Major limitations of the interim system are the following:

- a) Since it does not take into account such factors as running time, "false alarm" probability, the probability of detecting failures, repair effectiveness, and test coverage, only the apparent reliability is measured.
- b) The Reliability Trend Indices are carried only to the subsystem level.
- c) Data collection will be extremely cumbersome, since there is no central point where all reliability data are routed.

- d) The Flight Reliability Trend Index will be based on a limited number of tests since no additional flights will be conducted after completion of the Category III program.
- e) Subsystem interactions are not considered.

The limitations discussed herein can be overcome through implementation of the following recommendations.

5.2 Recommendations

The system described herein should be inaugurated on an interim basis, as a major step toward eventual attainment of an absolute reliability measurement capability.

Running time should be obtained in order that the interim reliability measurement system can be improved to provide an absolute measure of reliability, as opposed to a Reliability Trend Index.

Data collection and routing should be revised so that all reliability information is forwarded to a central location.

Models should be developed to a greater level of detail and reporting methods should be revised to support the more detailed equations.

DPL and countdown data should be collected throughout Operation Shakedown in accordance with the format proposed herein.

Analysis of controlled weapon system exercises should be conducted to establish:

- a) "False alarm" probability
- b) Probability of calling a bad system good
- c) Adequacy of test coverage
- d) Repair effectiveness

Periodic and cumulative reports in the format of Figure 5 should be instituted to assure proper dissemination of reliability data. Major areas requiring engineering action will thus be identified, assuring a more effective concentration of the engineering effort.

6. DEFINITIONS AND SYMBOLS

6.1 Definitions

Alert Readiness	The probability that a missile/launch complex will be nonfailed and capable of entering count-down; given that a launch directive is received at a random point in time after initial installation and checkout (average reliability during standby)
DPL	Dual Propellant Loading. As used here, a simulated launch countdown
EWO	Emergency War Order readiness. A missile/launch complex is in EWO if there are no observed failures and a target is assigned
Launch Countdown	The act of advancing an alert missile from standby through the point of liftoff
Periodics	Scheduled time periods during which scheduled maintenance occurs
Reliability	The probability that an initially nonfailed equipment will survive a specified time period under specified conditions
Reliability Trend Index (RTI)	An empirical measure of the ability of the weapon system or subsystem to survive a specified time under specified conditions based on the observed ratio of successes to trials for any given event or mode
Standby	A time period fixed by policy, for the duration of which the missile/launch complex is assigned to a target. It may be interrupted either periodically for scheduled maintenance or by the requirements of unscheduled maintenance
Successful Flight	A flight which occurs as programmed with impact within 3 C. E. P. of the designated target point
Successful Launch Countdown	A launch countdown which terminates in liftoff with no evidence of malfunction at that time

6.2 Symbols

D_g	D_i for guidance
D_i	Number of reporting time periods of length τ during the arbitrary time period T_s that the i^{th} subsystem was reported nonfailed for the entire time period τ .
M_{c_i}	Total number of launch countdowns and/or DPL's during which operation of the i^{th} subsystem was demanded
M_f	Total successful flights of the i^{th} subsystem
M_{f_i}	Total flights during which operation of the i^{th} subsystem was demanded
M_j	Total number of the j^{th} exercise
N_{c_i}	Total number of failures of the i^{th} subsystem in launch countdowns and/or DPL's
N_g	N_i for guidance
N_i	Number of time periods of length τ in an arbitrary time period of length T_s that the i^{th} subsystem experiences <u>one or more failures</u> , given that it was nonfailed at the <u>start of each time period τ</u>
N_{i_j}	Number of failed exercises, j , attributable to the i^{th} subsystem
P_{ar}	Apparent alert readiness probability for a continuous monitoring policy, without regard for schedules, periodic maintenance; depth of monitoring and quality of monitoring
$R_{cd}[G]$	Launch countdown Reliability Trend Index without regard for reaction time
$P_{cd}[G, t]$	Launch countdown Reliability Trend Index accounting for reaction time
$P_{cd}[t/G]$	Apparent probability of completing a launch countdown in a time " t " or less, given that the countdown terminates in a launch
R_f	Flight Reliability Trend Index
$R_g[\tau]$	$R_{s_i}[\tau]$ for guidance

R_{ij}	Reliability Trend Index for the i th subsystem during the j th exercise
$R_s[\tau]$	Reliability Trend Index of one missile/launch complex for any time τ during standby without guidance handover capability
$R'_s[\tau]$	Reliability Trend Index of one missile/launch complex for any time period τ during standby with guidance handover capability to any of "n" ground guidance centers, and without penalty for delayed reaction
$R_{si}[\tau]$	Reliability Trend Index of the i th subsystem for any time τ during standby
S_c	Number of launch countdown successes
S_f	Total successful flights
t_c	Reaction time constant
T_c	Number of launch countdown attempts
T_f	Total number of flights
t_r	Minimum reaction time
\bar{T}_r	Arithmetic mean of reported down times
T_{ri}	Duration of down time on i th occurrence
T_s	Scheduled duration of standby
τ	Least reporting time period in an arbitrary time period of length T_s
λ_s	Total system apparent failure rate (consumption rate) assuming independent, exponential failure distributions for all subsystems
λ_{si}	i th subsystem failure rate assuming an exponential failure distribution

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INTERIM D-SERIES ATLAS RELIABILITY MEASUREMENT SYSTEM, by members of the technical staff, Atlas Program Office. 29 June 1962. 44 p. incl. illus. (6301-6268-RU-000; RSD Exhibit 62-140)
(Contract AF 04(694)-3) Unclassified Report

This report describes an interim system for measurement of the reliability of the D-Series Atlas weapon system. Operational site and FMG Category III data are used for calculation of Reliability Trend Indices to the subsystem level in the standby, count-down and flight modes. A method for calculating Apparent Alert Readiness Probability from the same data is given. Data sources are identified and qualified, and data collection and processing methods are discussed. Sample exercises based on post-Golden Run data are contained in Secret Addendum A, STL 6301-6269-EZ-000, of this report.

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